Long-Term/High-Payoff's OMS IVHM Tested—First Pneumatic System With Fully Automated Checkout

W.T. Powers/EB22
205-544-3452
E-mail: wt.powers@msfc.nasa.gov

The use of single-stage-to-orbit (SSTO) technologies to reduce the operations costs for the X–33/RLV programs provides the opportunity to reduce the recurring production and refurbishment costs associated with the present external tank and solid rocket boosters on the Shuttle. However the implementation of SSTO dramatically increases the number of fluid components and complexity; fluids already represent the largest operational driver on the present orbiter. Several system level technologies (i.e. common commodities, EMA's, etc.) have been recommended to help reduce these operations costs; however there is still a need to address the recurring costs associated with checking out the fluid components every flight or during standardized maintenance periods. This requires on the Space Shuttle a large number of test ports, quick disconnects and ground support equipment to accomplish individual component checkout (fig. 103).

With the increased emphasis and planning on the use of integrated vehicle health management (IVHM) as a key to reducing operations costs on X–33/RLV, there is a need for real-life applications in genuine flight and operational environments. In addition, with the realization that the Shuttle will be flying many years before an RLV can replace it, many of these technologies can be cost effectively retrofitted on the shuttle. This IVHM system automates test and checkout requirements for the Orbital Maneuvering System/Reaction Control System (OMS/RCS) pneumatic systems that could take up to 1 week (2 shifts/day) and could require over 40 ground connections to the flight vehicle (quick disconnect (QD) mate, leak test each QD, etc.).

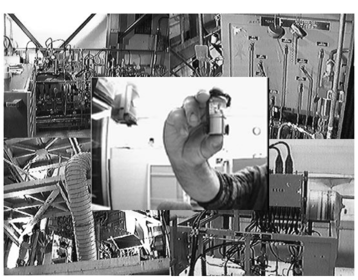

FIGURE 103.—Complex GSE replaced with small on-board components.

The Shuttle OMS/RCS, which has some of the most stringent operational checkout requirements, was chosen to demonstrate this technology. It is especially challenging due to its high usage of redundant components, the checkout requirements, and the lack of sensors with the data resolution/response required. This drives the current use of manpower and ground support equipment (GSE) intensive operations to perform all of the necessary checkout requirements. With existing instrumentation the required checkout data cannot be determined with just "in-flight" evaluation.

The operational and maintenance requirements specification document (OMRSD) for the OMS/RCS pneumatic components was used as the evaluation criteria for technical success/failure. The goal was to recreate ground checkout configurations without the need for hook-up of external GSE and be able to gather/analyze equal or better test data. Rockwell developed and demonstrated an on-board bias and vent control unit (OBVCU) which was used to create unique checkout configurations such as biasing open the primary regulator for second regulator checkout. This series of sensors and solenoid valves is a key to performing isolation valve, regulator, and check valve check out without GSE.

A VME-based system was used for data acquisition and control stimulus. Coupled with the new Taber transducers on board, very high data resolutions will be possible. The system will acquire, display and record a true 100+ Hz sample rate. The VME is connected to a Sun Ultra Sparc workstation running G2 a real-time expert system program (fig. 104). G2 runs the automated control and analysis sequences and provides the graphical user interface.

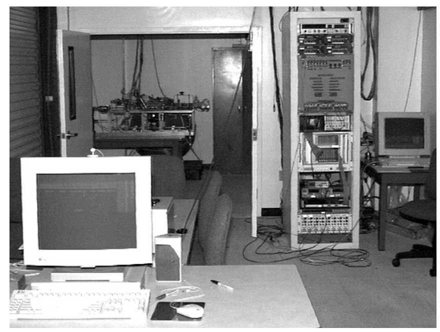

FIGURE 104.—Data acquisition and control system.

Regulator testing requires:

- Regulated flow within OMRS limits (272 +5 –7 for primary, 279 +5 –7 for secondary);
- Lock-up pressure below OMRS limits (281 for primary, 288 for secondary);
- Response with in 3 sec to regulated flow limits; and
- Creep test to verify regulator leak rate is below 720 SCCH sum.

There are dual regulars on the OMS/RCS helium pressurization system. One is an active primary and the other is a backup with a higher set-point that automatically takes over if the primary fails to open. Regulator checkout on the OMS/RCS can be one of the more time consuming portions of the OMS/RCS Helium pressurization checkout The primary regulators required two additional transducers (P5 and P8) with high data resolution) and high sample for checkout. The secondary regulators need additional instrumentation and require a mechanism to bias open the secondary regulator without hooking up external GSE. Our approach was to use the existing on-board pressurant to bias the primary regulators. With the OBVCU the secondary regulators can be biased open to perform secondary regulated flow, lock-up, response and creep tests. The use of the OBVCU tied to our advanced checkout system allows all regulator checkout on a pressurization system to be accomplished within 1 hr. There are eight systems which could be tested in parallel using this IVHM approach in no more than one shift. All regulator checkout has been automated and demonstrated on the on OMS IVHM test-bed. The only additional work is the testing of acoustic emission and ultrasonic as an alternate leak detection method.

Required testing for the isolation valves requires combined leakage (NMT 720 SCCH if 3 of 4 regulators are less than 360 and the other is less than 1200 SCCH).

The current approach to performing isolation valve leakage is to put a delta pressure transducer across the check valve to assure no flow across it and measure the rise in pressure between the isolation valves and check valve. If there is flow across the check valve, it is backed up with a higher pressure to preclude the flow. This requires our OBVCU to back up the valve in order to avoid external connections traditionally needed to accomplish this test, which is currently performed every flight. Acoustic emission sensors have been mounted to try assigning leakage magnitude to an individual valve (an OMDP requirement).

Required testing for check valves specifies reverse leakage (360 SCCH) and flow verification (NMT 2.5 PSID).

The OMS/RCS quad check valve presented a particularly challenging component to apply IVHM to because of the requirements for verification of redundant elements and the need to configure for reverse leak check. We used a single delta P connected directly to the intermediate test ports This pressure transducer is capable of withstanding 1,000+ lb/in^2 pressure surges and also provides a polarity (+ or –) that allows any blockage or stuck poppet to be isolated to either flow path. Acoustic emission sensors were used to detect flow in each poppet of the quad check valve.

The combined reverse leakage across all quad check valve poppets was challenging for IVHM application because it required purposely configuring for reverse leakage. Our approach was to use the OBVCU to blow down the section between the isolation valves and the check valve. This creates a reverse differential pressure similar to that produced by the GSE, and with the addition of the transducer P5 added between the isolation valves and the check valves, allows a combined reverse leakage to be determined.

Requires testing for check valves/burst discs specifies burst disk leakage — 0 allowable.

There is a combined burst disc and relief valve arrangement downstream of the regulators. The burst disc is checked every time the regulators are tested. The challenge here was avoiding the need to hook up the GSE. The approach was to combine the full range, high fidelity transducer with our 16-bit data acquisition. This test holds the best promise for application of acoustic emission or ultrasonic techniques since it requires a “leak/no leak” determination, not an actual quantification.

The OBVCU concept envisioned three valves used to either divert pressure to the regulators as a bias or vent to configure for leak checks.

Checkout is accomplished during any operational use. With this concept anytime the system is flowed is considered an opportunity to perform automated checkout. The operational times for OMS/RCS checkout are servicing, flight and deservicing. In this case the performance of automated checkout during deservicing holds the following advantages:

- The IVHM system can be driven by the ground checkout system alleviating the need to develop and implement expensive flight software/hardware changes.
- Since the OBVCU can only be activated on the ground its criticality and associated failure modes are much more benign. The goal is to not have to put special checkout requirements on the OBVCU itself.
- If there is a failure detected in the flight components (or the OBVCU itself) there is now sufficient time and resources to proactively address the problem at the beginning of the flow eliminate the need to make ground connections except to a deservice line.
- The required high flow rates specified by the current OMRS requirements (not nominally available in-flight) are achieved.

One of the concerns with applying IVHM was that the addition of numerous components would add to vehicle weight, increase complexity, and increase vehicle component failures. With the checkout panels/QD’s on the pods over 40 individual connections can be required during checkout. Each one must be leak checked and can obviously be a potential failure source. When addressed with the support GSE/facility, the judicious addition of a few sensors can look favorable in comparison. We have simplified the OBVCU concept at under 10-lb/pod.

A major issue that must be considered by any health management system is verification of the health of the instrumentation and data acquisition components. A variety of self-test and diagnostic techniques were applied to verify the health of the IVHM system.

G2, by Gensym, is being used as it readily supports the ability to quickly adapt the software from one test configuration to another with its flexible and rich syntax set. In designing the automated checkout software, object-based reasoning is utilized throughout. An intuitive GUI (fig. 105), which is both a real-time display and a system model, shows state and component attributes.The system records and automatically runs a statistical process control evaluation to determine out of family results, and performs a regression to predict future health of components.

The first fully automated checkout of a pneumatic system in a launch vehicle has been proven in an operational test-bed using off-the-shelf technologies (table 9).

As prior to this work no pneumatic system on a launch vehicle had ever been fully automated, this project demonstrates the feasibility of fully automating even heavily redundant systems using vehicle health management. Some of the general conclusions components reached are:

- Vehicle health management emphasis should shift from a focus on in-flight checkout to checkout through operational use (flight, service, de-service, etc.).
- With the application of IVHM the use of redundancy to increase overall mission reliability need not entail increased and complex test and checkout requirements.
- Through the judicious choice of when and how IVHM components are applied, they need not significantly increase vehicle LRU replacement rates, add additional failure points, engender new checkout requirements for the IVHM system itself, increase weight, etc. In addition, when the overall system (vehicle plus ground structure) including the facility, GSE, test ports, etc. are considered, IVHM can dramatically reduce system complexity, cost, failure rates, etc.
- All of the frequent checkout requirements on the OMS/RCS could be performed using IVHM techniques made up of off-the-shelf components and/or proven technology. Most of the innovation was at the integration and application level. This holds the promise of near-term application to vehicles such as X–33 or the Shuttle.
- Many of the component or element testing (such as element test reverse leak check of the quad check valve) performed at intermediate or depot maintenance periods such as OMDP on the orbiter were not readily solvable with off-the-shelf or proven instrumentation techniques. The application of yet unproven nonintrusive techniques such as acoustic emission, Hall effect, etc. hold the best hope for addressing these requirements.
- The philosophy of checkout through operational use versus only in-flight checkout allows much of the IVHM software to reside on the ground system. This means the software is more amenable to upgrades, changes, reduced maintenance costs, etc.
- The collection and saving of test data/results allows for the potential correlation of past data to predict the future health of the component versus several failure modes. This demand management system allows for proactive replacement of failing parts, logistics stocking and replenishment based on actual component health, identifying of anomalous trends across vehicles, etc.

Table 9.—*OMS/RCS frequent checkout and required IVHM.*

Technique Test	High Res X-Ducer's	100 Hz Sampling	P5 0–400	P8 0–400	P2 0–100	ΔP 0–15	T5	T8	OBVCU Valves	Expert S/W
Prime Regulators										
• Flow			X							X
• Lock-up			X							X
• Response		X*	X							X
• Creep	X		X	X			X	X		X
Secondary Regulators										
• Flow			X						X	X
• Lock-up			X						X	X
• Response			X						X	X
• Creep	X	X*	X	X			X	X	X	X
Iso Valves										
• Leak	X		X	X			X	X	X	X
Check Valve										
• Flow						X				X
• Rev. Leak	X		X	X			X	X	X	X
Burst Disk										
• Leak	X				X					X

Sponsor: RLV—Long-Term/High-Payoff Technologies Program

Biographical Sketch: W.T. Powers is a senior measurement systems engineer in the Instrumentation Branch of the Astrionics Laboratory of MSFC. He holds a bachelor of science degree in electrical engineering, and minors in mechanical, nuclear and physics from Tennessee Polytechnic Institute. He has 33 years of service with NASA and primarily deals with the development of advanced sensors and measurement, acquisition, and processing systems.

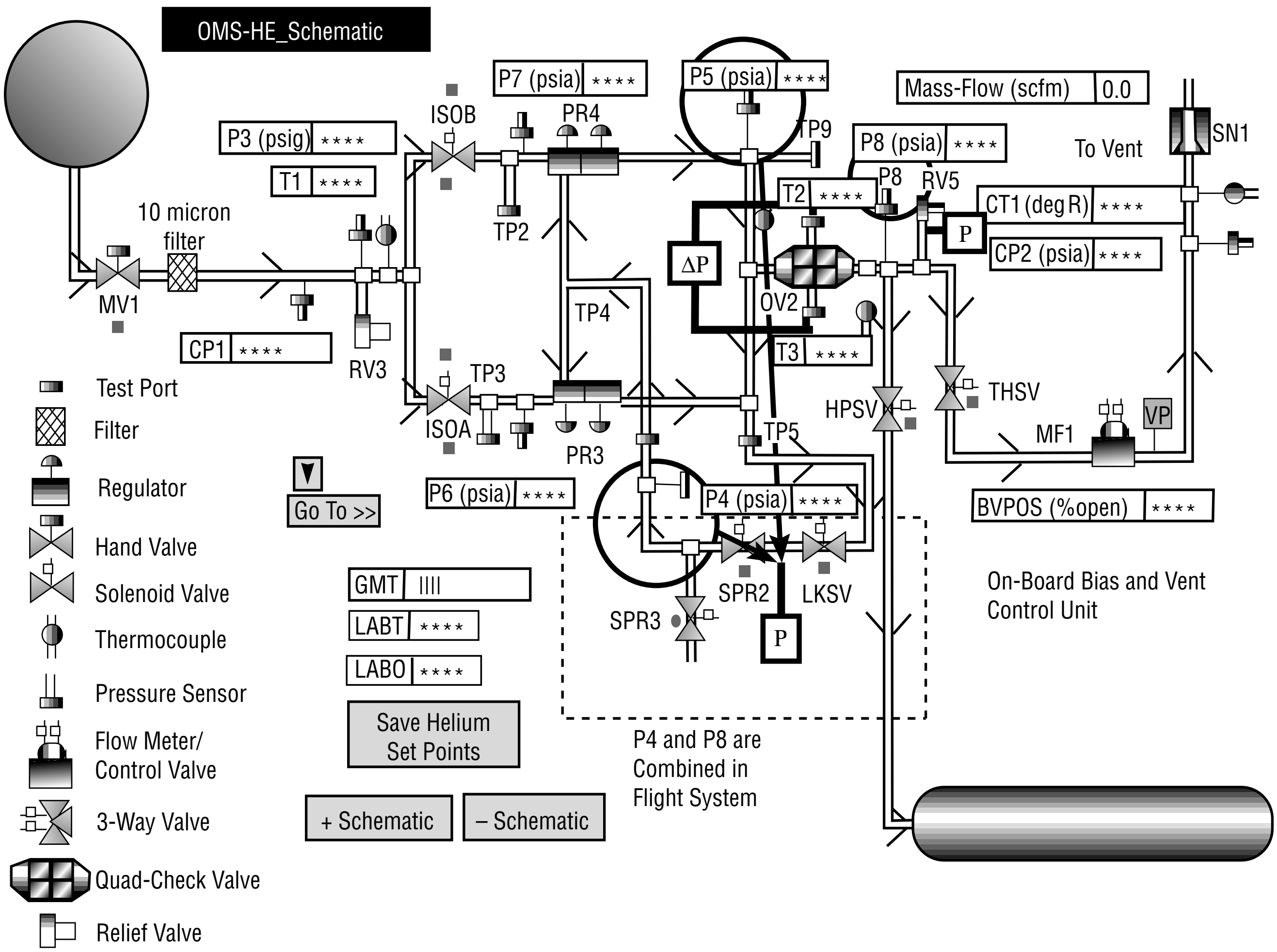

FIGURE 105.—OMS IVHM expert system screen.